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AUTHOR(S):

Nakahara, Akio; Matsuo, Yousuke

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Control of crack formation by using memory of paste

Lab. of Physics, Coll. of Science and Technology, Nihon Univ.

Akio Nakahara¹ and Yousuke Matsuo

粉と水を混ぜて作ったペーストを乾燥前に揺すっておくと、ペーストは揺すった方向を記憶し、乾燥時に発生する亀裂パターンは揺すった方向に依存した縞状パターンになることが実験的に得られた。縞状亀裂パターンの方向は多くの粉では揺すった方向に垂直であるが、炭酸水酸化マグネシウムの場合粉の体積比を減少させると縞状亀裂パターンの方向が垂直方向から平行方向へと転移する現象が観察された。この平行縞の方向は揺すった時に発生した流れの方向と同じなので、この現象を利用し亀裂パターンを自在に制御できるようになった。

1. Imprinting memory into paste

We prepare a paste by mixing powder of calcium carbonate with water. When we dry the paste, we usually obtain isotropic cellular crack pattern. When we vibrate the paste horizontally for a short time before drying, however, the paste remembers the direction of the initial external vibration, and the lamellar crack pattern appears with directions of these cracks all perpendicular to the direction of the initial vibration [1-2]. By making morphological phase diagram of crack pattern and by performing rheological measurement of the paste, we find that due to its plasticity the paste remembers the density fluctuation of densely packed particles induced by vibration.

2. Transition of memory and its visualization as crack patterns

When we use magnesium carbonate hydroxide as powder, we find in Fig. 1 that the direction of lamellar cracks changes from perpendicular direction to parallel direction when compared with the direction of the initial vibration.

The transition of the direction of lamellar cracks is also observed in the morphological phase diagram of crack patterns shown in Fig. 2. Changing the shape of container as in Fig. 3, we find that the direction of the new type of lamellar crack in region C of Fig.2

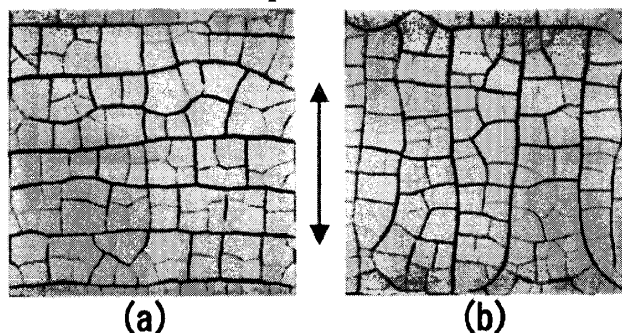


Fig.1 Transition of the direction of lamellar cracks. The arrow indicates the direction of the initial vibration with the strength of 2.4m/s^2 . The solid volume fraction ρ is 12.5% in (a) and 6.7% in (b), respectively. Decreasing the value of ρ , the direction of lamellar cracks changes from perpendicular direction in (a) to parallel direction in (b) [3].

¹E-mail : nakahara@phys.ge.cst.nihon-u.ac.jp

is not always parallel to the direction of vibration, it is rather parallel to the direction of the flow induced by the initial vibration. As we consider that the crack pattern is a visualization of memory contained in paste, we find that the transition of memory is induced by decreasing the value of the solid volume fraction at the initial vibration.

Then, why there appear a transition of memory in paste? We find that the shape of magnesium carbonate hydroxide particles is disk-like, while that of calcium carbonate is roughly spherical. Thus, as for paste made of magnesium carbonate hydroxide, card house structure built of disk-like particles and also the lack of Coulombic repulsive interaction among particles enable the formation of dilute network structure with plasticity even at low solid volume fraction. That is why paste made of magnesium carbonate hydroxide can remember the direction of flow at low solid volume fraction. We consider that the flow is memorized as an elongated stripe-like microstructure with disk-rearrangement under flow.

Since paste can remember flow pattern, we can design various crack patterns, such as ring, spiral, etc., by changing shapes of containers and also by changing the way to apply mechanical forces.

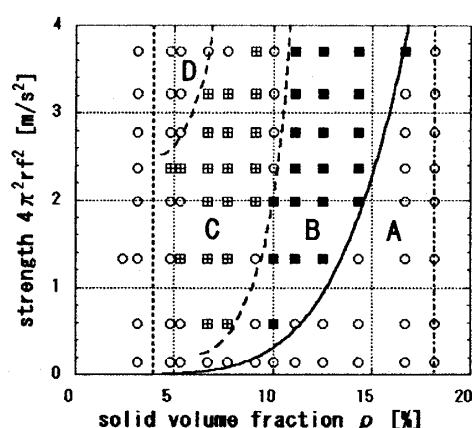


Fig. 2 Morphological phase diagram of crack patterns, shown as a function of the solid volume fraction ρ and the strength of the initial vibration. Open circles denote isotropic cellular crack patterns, solid squares denote lamellar crack patterns, the direction of which is perpendicular to the direction of the initial vibration, and squares with plus inside denote lamellar crack patterns, the direction of which is parallel to the direction of the vibration [3].

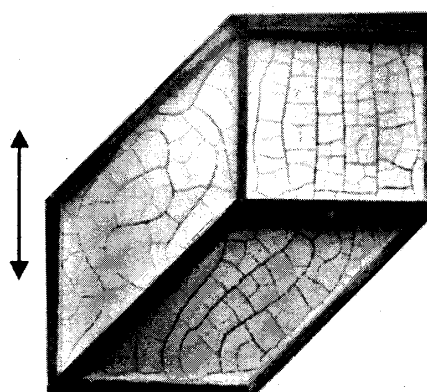


Fig. 3 Experiment to investigate the feature of the new type of lamellar crack in region C of Fig. 2. Here, the solid volume fraction ρ is 7.7%. The arrow indicates the direction of the initial vibration with the strength of 0.6 m/s^2 . We see that flow patterns caused by the initial external vibration are memorized and are visualized by crack patterns [3].

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